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TECHNICAL NOTE

D-1287

EXPERIMENTAL INVESTIGATION OF WATER-ABSORBENT MATERIALS AS POSSIBLE HEAT SINKS FOR HYPERSONIC AND REENTRY VEHICLES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON July 1962

E-939

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SUMMARY

Porous materials saturated with water were considered for cooling low-melting-temperature structural materials in the less severely heated areas and for thermal protection that would provide suitable environmental temperatures for payloads, such as instrument packages or human occupants.

The water-absorbing mediums investigated included such materials as balsa wood, diatomaceous earths, foamed plastics, vermiculite, absorbent paper, and felts of glass and quartz microfibers. Tests that were made to determine the water-absorption capabilities of these materials indicated that the quartz felt (6.0 lb/cu ft) absorbed the greatest amount of water. (The unit volume of the material was measured when the material was wet.) The diatomaceous earth products were far superior to the other materials in their capacity to retain the absorbed water when the materials were subjected to acceleration loads up to 15 g's. When the materials were subjected to simulated aerodynamic heating of about 1/2 Btu per second per square foot, the diatomaceous earth product (13.5 lb/cu ft) afforded more temperature protection. On the basis of an overall evaluation, the best choices of the porous materials investigated were a diatomaceous earth product and the 6.0-pound-per-cubic-foot quartz felt.

INTRODUCTION

Vehicles flying at hypersonic speeds in the atmosphere will encounter two levels of aerodynamic heating. On leading edges and portions of the afterbody the heating will often be so severe that the resulting equilibrium temperatures will be too high for most engineering materials. These surfaces must either be cooled or made of refractory materials. Away from the leading edges, equilibrium temperatures will usually be within the temperature capability of present-day superalloys. Cooling the outer skin of the vehicle may therefore be unnecessary. Internal cooling, however, will be necessary to provide thermal protection either for low-melting-temperature structural materials or for payloads. For this purpose, water, when held in place by a porous medium, shows good promise as a heat sink. The results of an experimental investigation of a number of available absorbent materials used as the water carrier for this type of heat-sink application are presented herein.

Water, when heated and vaporized at ambient conditions of temperature and pressure for altitudes up to at least 200,000 feet, absorbs approximately 1100 Btu per pound. In order to use water as a heat sink, some means must be provided to maintain the water distribution necessary for optimum cooling over the surface, or surfaces, of the protected vehicle. An absorbent or "blotter-like" material was suggested in reference 1 to maintain this distribution. To function properly in such a heat-sink cooling system, a water-absorbent material should: (1) be lightweight, (2) readily absorb and equally distribute a large amount of water, (3) withstand acceleration loads encountered in flight with only a small or negligible loss of absorbed water, (4) release the absorbed water by evaporation under the heat loads that would be imposed by aerodynamic heating, and (5) preferably be rechargeable to enable its repeated use.

A practical limiting temperature for present-day superalloys that might be used for the outer skin in the afterbody region of hypersonic vehicles is approximately 1800° F. Temperatures as low as 250° F will be required in the afterbody region to protect lightweight structural materials such as aluminum and magnesium. In order to protect either human occupants or delicate instruments, it may be necessary to maintain internal temperatures as low as 75° F. Reference 1 suggests a method for internal cooling in which a layer of insulating material and a layer of water-saturated heat-sink material are placed between the aerodynamically heated outer skin and the structural member or payload.

An experimental program was initiated to screen existing water-absorbent materials known to have physical characteristics that appeared to be desirable for the intended heat-sink application. A number of the more promising materials were subjected to further evaluation. The water-absorption characteristics and the ability of the materials to retain the absorbed water under acceleration loads as high as 15 g's in a centrifuge were determined. Tests were also conducted in a heating apparatus in an effort to determine the effectiveness of water-saturated materials as heat sinks under simulated heating conditions representative of those that would be encountered in hypersonic vehicles. Three variations in the method of discharging the resultant steam were investigated.

HEAT-SINK SYSTEMS

Water will absorb approximately 1100 Btu per pound when heated and vaporized under ambient conditions of temperature and pressure for altitudes up to at least 200,000 feet. Additional heat absorption can be obtained by superheating the resultant steam. A plan was proposed in reference 1 for utilizing this heat capacity of water as the heat sink for portions of the afterbody of hypersonic aircraft and reentry vehicles. The proposed plan assumes a maximum outer skin temperature of 1800° F while maintaining an internal-structural-member temperature of about 220° F. At this relatively low temperature level, water is an effective heat sink if permitted to vaporize. The resultant heat flux for such a system with the prescribed temperatures would be approximately 1/2 Btu per second per square foot if the water-absorbent heat-sink material is separated from the outer skin by a 1-inch thickness of commercially available, low thermal conductivity fibrous insulation. Under these conditions, 1 pound of water per square foot of surface area should provide approximately 35 minutes of protection.

A problem in cooling an aerodynamically heated structure with water is the uniform distribution and retention of the water in the regions that require cooling. Various methods have been proposed to solve this problem. A simple, low-weight system that was proposed is one in which the water is contained in an absorbent material placed between the heated outer skin and the supporting structure. Saturated balsa wood was suggested for this purpose (ref. 1). One such system is shown schematically in figure 1(a). In this system, the aerodynamically heated outer skin is backed with a high-temperature fibrous insulating material to effect an initial temperature drop between the outer skin and the heat sink. A moisture barrier separates the fibrous insulation from the water-absorbent heat-sink material. The load-bearing member of the aircraft structure with suitable vents for the evaporated water is on the upper side of the heat sink. No mechanical connection is shown in figure 1 between the outer skin and the structural member of the vehicle, although a practical system must have such connections. Evaluation of design features of this nature, however, is beyond the scope of this investigation.

The temperature of the load-bearing member can be kept at the boiling point of water as long as there is water present in the absorbent heat-sink material. Within certain limits, this temperature can be controlled by the pressurization imposed on the venting system.

The heat-sink systems shown in figures 1(b) and (c) are variations in the arrangement of the basic elements used in the heat-sink system of figure 1(a). In the heat-sink system of figure 1(b), the fibrous insulation is separated from the water-absorbent material by a space for venting the resultant steam. This system makes more efficient use of the absorbed water by forcing the steam to vent through the heated side of the heat-sink material, thereby, taking advantage of the additional heat absorption available through superheating the steam. The heat-sink system of figure 1(c) allows the steam to vent back through both the heat sink and the insulation material to a space separating the outer skin from the fibrous insulation to obtain additional superheating of the steam. The presence of the steam in the insulation, however, may change the thermal conductivity of the insulation.

WATER-ABSORBENT MATERIALS

To function properly in the cooling system of a hypersonic or reentry vehicle, a water-absorbent heat-sink material should (1) be lightweight, (2) readily absorb and equally distribute a large amount of water, (3) withstand acceleration loads representative of those that would be encountered in flight with only a small or negligible loss of absorbed water, (4) release the absorbed water by evaporation under the heating loads imposed by aerodynamic heating, and (5) preferably be rechargeable for repeated use.

A number of existing materials were screened for possible use in this application. Some of the more promising materials (shown in fig. 2) were:

(a) Balsa wood of about 6.0 pounds per cubic foot in the form of sheets, which was commercially available, and four- and seven-layer plywood. The balsa plywoods were considered because the balsa-wood sheets warped so severely. (See APPARATUS AND PROCEDURE section for description of fabrication.)

(b) Standard commercial sheet blotter paper, such as that available in a stationery store, stacked together without a bonding agent. Approximately 16 sheets of this blotter paper measured 1/2 inch in thickness when saturated with water.

(c) Vermiculite (1/8-in. granules), an expanded form of mica.

(d) Diatomaceous earths in the form of two commercial pipe insulations (available in 1/2-in.-thick sheets). One type, weighing 23.9 pounds per cubic foot, contained asbestos fibers, diatomaceous silica, and an inorganic binder. The other, weighing 13.5 pounds per cubic foot, contained asbestos fibers, diatomaceous silica, and lime.

(e) Commercially available porous foamed phenolic plastic in three densities (1.5, 2.1, and 3.3 lb/cu ft). These specimens had been treated with a wetting agent by the supplier.

(f) Glass felt, a lightweight (approximately 4.0 lb/cu ft) flexible felt generally used for insulating purposes at temperatures up to 1000° F. It is composed of microfibers ranging from 0.05 to 3.8 microns in diameter, is made from a borosilicate type of glass, and is commercially available in various thicknesses.

(g) Quartz felt, a lightweight, flexible felt, generally used for high-temperature (up to 2000° F) insulating applications, in two densities (3.5 and 6.0 lb/cu ft). It is composed of microfibers of pure quartz averaging 1 micron in diameter and is commercially available in various thicknesses.

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APPARATUS AND PROCEDURE

Specimen Preparation

The only specimens that required any preparation or fabrication before testing were the four- and seven-ply balsa specimens. Balsa sheets were cut into 1/8-inch and 1/16-inch layers to form the four- and seven-layer balsa plywoods. In fabricating the plywoods, alternate layers were so arranged that the grain of the wood was at right angles. A waterproof glue was used to cement the layers together and form 1/2-inch-thick specimens. The plywood specimens were perforated (see fig. 2) with holes 1/16 inch in diameter that were spaced 1/4 inch apart. Because the glue acts as a water barrier between the plies, the perforations were considered necessary to facilitate the absorption of water by the balsa layers and also to facilitate the release of this absorbed water by evaporation when under heating loads.

Absorptivity Tests

Samples of all the materials investigated were submerged in water at room temperature and pressure for several hours to determine their water-absorption capabilities. Some of the materials were also subjected to a temperature-pressure process, in which the samples were submerged under boiling water in a steam chest and pressurized at 15 to 20 pounds per square inch gage (about 280° F) for approximately 1 hour. This treatment increased the absorptivity of the balsa-wood materials greatly and the absorptivity of vermiculite to some degree, but it apparently did not alter the absorption properties of the other materials. While submerged in water at room temperature, the absorptivity of samples of balsa wood that were subjected to pressures as high as 100 pounds per square inch gage was slightly greater than that of samples treated at room pressure.

The amount of water absorbed was determined by the weight change from the dry to the wet condition. The weight per unit volume of both wet and dry samples was based on the wet volume. Only two materials, blotter paper and balsa wood, showed appreciable increases in volume due to wetting. The size of each test specimen used for the absorptivity tests was approximately 100 cubic inches. Although specimen sizes varied somewhat, this variation had no effect on the results because the absorptivity was based on a unit volume.

Water Retention Under Acceleration Loads

Centrifuge tests were performed on samples of the various heat-sink materials in order to determine their abilities to retain the absorbed water under acceleration loads representative of what might be imposed on hypersonic aircraft or reentry vehicles. A schematic diagram of the apparatus used for these centrifuge tests is shown in figure 3. The acceleration load tests were conducted on samples 2- by 3- by 1/2-inch in size, with the load applied across the 1/2-inch dimension. The sample holder in this apparatus was constructed of a heavy-wire-mesh frame, which permitted the escape of water that was ejected from the sample under centrifugal load. A box enclosed the heavy-wire-mesh frame to ensure that no air-drying of the sample occurred during the test. A sump at the outer edge of this closed box trapped the ejected water. Vermiculite, the only loose material investigated, was enclosed in 2- by 3- by 1/2-inch fine-wire-mesh baskets before it was placed in the apparatus for water-retention testing. The combination of shaft speeds and two radius-arm locations (2.6 and 4.0 ft) provided a means for simulating load conditions of approximately 3, 5, 9, and 15 g's. Centrifuge tests of 1-, 3-, and 5-minute duration were used. The amount of water lost was determined by the difference in weight of the sample before and after each test time interval.

Heat Tests

The electrical heating apparatus shown schematically in figure 4 was used to evaluate the effectiveness of the proposed variations in the arrangement (fig. 1) of insulation, heat-sink material, and steam venting; and to determine the usefulness of each material as a possible heat sink. Figure 4 illustrates the system proposed in figure 1(a). The apparatus was modified to test the other proposed systems.

The heat-test apparatus used an electrically heated 1/16-inch-thick Inconel plate with a 12- by 14-inch surface to simulate an aerodynamically heated outer skin. The plate was bolted between terminal strips and formed an integral part of the secondary circuit of the power transformer used in heating the simulated outer skin. Power for the primary circuit was taken from a 110-volt, 150-ampere electrical supply. The heater plate was lined on the sides and undersides by insulating fire brick to minimize heat losses. The fibrous insulating material used in all the arrangements tested was a 1-inch thickness of low-conductivity, refractory-fiber felted pad, which has a dry density of 3.0 pounds per cubic foot. When necessary, a thin sheet of Inconel was used to simulate a moisture barrier. A 1/8-inch sheet of Inconel was used to simulate the structural member of the aircraft. In the case of the arrangement shown in figure 1(a), the Inconel sheet was perforated to allow steam to vent from the heat-sink material. The water-saturated test specimens used in all the heating tests were approximately 14- by 16- by 1/2-inch thick and were prepared in the same manner as for the absorptivity tests described previously. In all arrangements, a 1/2-inch space was provided to allow for the escape of steam generated in the heat-sink material.

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Thermocouples were installed on various parts of the heat-test apparatus in order to measure the temperature levels of these parts when simulated heating loads were applied to the heater plate. Thermocouples were arbitrarily placed on the surface of the heater plate to measure lateral and longitudinal temperature distributions. Similar temperature distributions were measured at the moisture barrier and on the simulated structural member.

The simulated outer skin was heated to an average temperature of 1800° F and held at this level for the duration of the test. A thermocouple at the center of the plate was connected to a temperature controlling unit in order to maintain this temperature level. The heating tests were continued until an appreciable area (approximately 10 sq in.) on the simulated structural member reached a temperature greater than 220° F. This condition indicated that the heat-sink material immediately beneath this area of the plate was no longer releasing water for evaporation. The time required to reach this condition was a measure of the effectiveness of the test material as a heat sink. During a heating cycle, the water in the heat-sink material is heated and eventually vaporized; approximately 1100 Btu per pound is absorbed in the process.

RESULTS AND DISCUSSION

Weight and Absorptivity

The bar graph of figure 5 shows the total densities of the water-saturated materials investigated. The dotted areas of the bars represent the weight of water absorbed per cubic foot of wet material. The crosshatched areas indicate the dry density of the materials (adjusted to wet volume). The scale at the bottom of the figure is used with the dotted areas of the bar graph only. This scale shows the volume of water absorbed by the material compared with the amount of water that could be contained in a unit volume if the absorbent material were not present (100 percent).

The dry densities of the materials varied from 23.9 pounds per cubic foot for the heavier form of diatomaceous earth to 1.5 pounds per cubic foot for the lightest of the foamed plastics. All the materials, with the exception of vermiculite, absorbed more than 48 pounds of water per cubic foot of material. This is more than 75 percent of the maximum amount of water that could be contained in that volume. The 6.0-pound-per-cubic-foot (when dry) variety of felted pads of quartz microfibers absorbed the most water per unit volume, 60.1 pounds per cubic foot or about 95 percent of the maximum amount possible. The percent of total weight of the materials when saturated with water due only to the absorbent material varied from 2.8 for the lightest foamed plastic to 32.1 for the heavier form of diatomaceous earth product.

Water Loss Under Acceleration Loads

The results of the centrifuge tests on the various materials are shown as the percent of water lost during 1, 3, and 5 minutes under loads of approximately 3, 5, 9, and 15 g's in figure 6. In general, the denser materials lost the lower percentages of absorbed water. Under a 5-g loading for 5 minutes (a practical limit for manned vehicles), only three materials (vermiculite, glass felt, and 3.5 lb/cu ft felt of quartz microfibers) lost more than 5 percent of the absorbed water. The best materials with respect to water retention were both the light and heavy forms of diatomaceous earth products. Each of these materials lost less than 3 percent of the absorbed water under the most severe condition tested (15-g load for 5 min).

The degree of this water loss under acceleration loads will vary with the nature of the vehicle and the cooling-system design involved. With the proper cooling-system design and a water-absorbent material that has good wicking action, much of the displaced water may be retrieved or redistributed after the acceleration load is removed. If the water is not retrievable by wicking action, these losses could be compensated for by increasing the initial quantities of water-saturated heat-sink material contained in the system. Figure 6 shows the magnitude of such losses for which compensation would have to be made.

Heating Tests

Table I presents a tabulation of heating times for all the materials tested under the heating condition of a constant plate temperature of 1800° F for the heat-sink system shown in figure 1(a). The heating time was measured from the moment electric power was applied to heat the simulated outer skin until a time when temperatures in excess of 220° F over an area of approximately 10 square inches were reached on the perforated plate directly above the heat-sink material.

All parts of the heating apparatus were at room temperature at the beginning of this time period. Approximately 7 minutes were required to raise the "outer skin" temperature to 1800° F. The listed heating times vary from a minimum of 73 minutes for vermiculite to a maximum of 132 minutes for the heavier form of diatomaceous earth product. When tests were duplicated, the results were in good agreement with those of previous tests.

Figure 7 presents a comparison of the results of these heating tests based upon a heating-time factor (ratio of the length of time a specific material functioned as a water retainer to the weight of the wet material per sq ft for a 1/2-in. thickness). Such a comparison shows which water-saturated heat-sink material will provide thermal protection for the longest time with the least weight. Where more than one test was made on a specific material, the average heating-time factor is presented. As can be seen from figure 7, the heating-time factors of all the materials were in a rather narrow range between about 38.4 and 44.6 minutes per pound of wet material per square foot. All the heating-time factors, therefore, lie within a range that has a midpoint value of 41.5 with a spread of only $\pm 7\frac{1}{2}$ percent. On the basis of heating-time factor alone, the best material tested was the lighter form of diatomaceous earth product. During the screening operation of this investigation, diatomaceous earth in powder form was also considered. This material did not absorb as much water and it did not have as good a heating-time factor as those of the other diatomaceous earth products tested. The values of the heating-time factors reported herein may differ somewhat from those of reference 2. Based on additional testing and a reevaluation of previous test data, the values reported herein are considered more representative.

The diatomaceous earths, vermiculite, and the felts of glass and quartz microfibers had the advantage of being rechargeable after heating. All the other materials were destroyed during one heating cycle. When heated, foamed plastics charred, cracked, and shrank and allowed heat to flow directly through to the simulated structural member. The balsa plywoods charred badly; the 1/2-inch balsa sheets not only became charred but also became distorted so that they no longer formed a continuous barrier to the flow of heat. The other nonreusable material, blotter paper, was gradually consumed as it progressively dried out from the lower surface to the upper surface.

A comparison of figures 5 and 7 shows that there is no correlation between the percent of water absorbed and the heating-time factor. For this reason, the effectiveness of a material as a water-absorbent heat sink cannot be judged solely on the basis of the amount of water absorbed.

All heating times and ,therefore, heating time factors for heat-sink system 1 (see fig. 1(a)) were determined when the temperatures on the perforated plate (simulated structural member) exceeded 220° F. Some tests were made to determine the advantage of considering the cover plate directly above the area for venting steam as the support structural member rather than the perforated plate (fig. 1(b)). Thermocouples were located on this plate in much the same manner as those on the perforated plate, and a layer of insulating material was placed on top of this plate to simulate an actual application. The tests indicated that an average of 15 to 20 minutes could be added to the reported heating times when the cover plate was considered as the structural member to determine the termination of testing. The tests were terminated when a number of thermocouples on this upper plate (an area of approximately 10 sq in.) exceeded 220° F.

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Two materials, glass felt and the lighter form of diatomaceous earth product, were used for evaluating the three heat-sink systems shown in figure 1. These materials were chosen because they were reusable, easy to handle, and of a uniform or homogeneous composition, so that the water absorbed by the material was uniformly distributed. Table II shows the results of the heating tests for the three heat-sink systems (fig. 1) under the condition of an 1800° F simulated outer skin temperature. A comparison of these results was based on the heating-time factor. As indicated in table II, the heat-sink system proposed in figure 1(b) has a much higher heating-time factor than the other two systems investigated; it would, therefore, provide protection from aerodynamic heating for a much longer time. Heating-time factors obtained for system 2 were approximately twice as large as those obtained from heating tests with system 1.

System 2 makes more efficient use of the absorbed water in the heat-sink material by allowing the resultant steam to vent at the heated side of the heat-sink material into a space separating the heat sink from the fibrous insulation. Additional heat-absorption capabilities of the absorbed water are utilized by superheating the resultant system, whereas in system 1 the steam is vented above the heat-sink material without being superheated. System 3 (fig. 1(c)) allows the resultant steam to pass through both the heat-sink and fibrous-insulating material before venting to a space separating the simulated heated outer skin from the insulating material. Venting at a location of higher temperatures should allow the steam to absorb more heat than it would in systems 1 and 2. As indicated in table II, however, the heating-time factors for this heat-sink system are not much higher than those for system 1 (approximately 12 percent higher) and are much lower than those obtained for system 2. The cause of these low values for this system is not clear; however, the presence of the steam in the fibrous insulating material might have had an adverse effect on its thermal conductivity, which resulted in unexpectedly low heating-time factors.

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Final Evaluation

The results of this investigation show that water-saturated heat-sink materials are feasible for absorbing the heating loads that will exist on the afterbody of hypersonic aircraft and reentry vehicles. None of the materials investigated satisfied all the desirable characteristics previously discussed, namely, lightweight, high absorbtivity, minimum loss of water under centrifugal load, long-time thermal protection, and reusability. In addition, consideration must be given to the cost, the ease of preparation for intended use, ease of handling and loading with water, and uniformity of composition. A final evaluation requires the simultaneous consideration of all these features.

The heating-time factors presented do not include the loss of water from the saturated materials when under acceleration loads. If it is assumed that the heating-time factors would be reduced in proportion to the amount of water lost, a rough estimate of this effect can be made by means of figure 6. For example, under a 5-g load for 1 minute, vermiculite loses 8 percent of its absorbed water. If a proportional decrease in the heating-time factor of 8 percent is assumed, the adjusted heating time factor is 40.3 while the reported value is 43.8 minutes per pound of wet material per square foot. When similar corrections are made for the other materials, the diatomaceous earth product, which has the highest reported heating-time factor, looks even more favorable because of its extremely high water-retention capabilities.

Because they had to be given the boiling-water treatment first, the vermiculite and all forms of balsa material were difficult to load with water. With this treatment the water-absorption capabilities of the balsa forms were increased approximately 400 percent and those of the vermiculite were increased 25 percent. In addition, the preparation of the perforated balsa plywood forms was involved. The foamed plastics, although light in weight and absorbing water fairly well, were all quite weak and brittle. The vermiculite and the felted materials (except the 6.0 lb/cu ft variety of quartz felt) lost appreciable percentages of the absorbed water under acceleration loads.

Rechargeability of the heat-sink materials is very desirable for vehicles that will make more than one flight. Use of nonrechargeable materials would necessitate design features that would permit the removal of the outer skin and the replacement of the consumed heat-sink material. This feature would involve additional weight and complexity. Of the materials tested, the diatomaceous earth products, the vermiculite, and the glass and quartz felts were rechargeable.

When all factors are considered, the diatomaceous earth products and the 6.0-pound-per-cubic-foot quartz felt appear to be the best of all the materials investigated. The diatomaceous earth products have a relatively high heating-time factor (approximately 44); their water loss under acceleration loads is extremely low (see fig. 5); they are easily saturated; and they are reusable (although the lighter form of this material did exhibit cracks after being subjected to a number of heating cycles). The forms of diatomaceous earths investigated were rather heavy materials; the lighter form weighed approximately 13.5 pounds per cubic foot and the heavier form weighed approximately 23.9 pounds per cubic foot. These are tare weights of approximately 1/5 and 1/3, respectively, of the total wet weight of the materials. Inasmuch as the diatomaceous earths have a high heating-time factor, the rather heavy dry weights of these materials become detrimental only when the materials are used in vehicles that would remain airborne for an appreciable length of time after the water had been consumed. Some problems may also exist in forming, molding, or shaping the material to the required contours.

Quartz felt, conversely, is very flexible and conforms to almost any contour. In addition, quartz felt is relatively light in weight (6.0 lb/cu ft), is saturated rapidly, has high temperature (up to 2000° F) insulating capabilities, and can be used repeatedly without any apparent detrimental effects to its heat-sink capabilities. When subjected to acceleration loads, this material has a somewhat greater loss of water than the diatomaceous earths, and it has a relatively low heating-time factor.

The scope of this investigation was limited to materials that were known either to be available or easily fabricated. It is very possible that the optimum type of material was not included in the group described herein. Such a material may be found or developed with further investigation.

SUMMARY OF RESULTS

The following results were obtained in an experimental investigation of several existing materials as possible water-absorbent heat-sink materials for use in the cooling of the afterbody regions of hypersonic and reentry vehicles:

1. It appears that water-saturated absorbent materials are feasible for absorbing the aerodynamic heating loads on certain parts of hypersonic aircraft and reentry vehicles.

2. All the materials investigated, with the exception of vermiculite, absorbed at least 48 pounds of water per cubic foot of material. This represented more than 75 percent of the maximum amount that could be contained in that volume. The 6.0-pound-per-cubic-foot form of quartz felt absorbed the most water (approximately 60 lb/cu ft or 96 percent of the maximum amount possible).

3. The best materials with respect to minimum water loss when subjected to acceleration loads were the diatomaceous earth products. Under a 5-g loading for 5 minutes (a practical limit for manned vehicles), only three materials (vermiculite, glass felt, and 3.5-lb/cu ft quartz felt) lost more than 5 percent of the absorbed water.

4. During a heating test in which the outer skin temperature was 1800° F and the resultant steam discharged from the cold side of the heat sink (system 1), the lighter form of diatomaceous earth product exhibited the best heating-time factor (time of protection per unit weight of wet heat-sink material). The average heating-time factors for all the materials, however, were in a rather narrow range between 38.4 and 44.6 minutes per pound per square foot for a 1/2-inch thickness of wet material.

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5. No correlation was obtained between the percent of water absorbed and the heating-time factor for the various materials.

6. Of the three systems proposed for providing internal cooling of a hypersonic vehicle, the system in which the heat-sink and insulating materials were separated by a space for venting steam (system 2) proved to be a much more efficient method for taking advantage of the heat-absorption capabilities of the steam generated in the saturated heat-sink material. Tests conducted with glass felt and the lighter form of diatomaceous earth product indicated that the heating-time factors for this system were approximately twice the values obtained for the other systems investigated.

7. Of the materials considered, the diatomaceous earths, vermiculite, and the felts of glass and quartz fibers were rechargeable for repeated use.

8. On the basis of an overall evaluation in which absorptivity, water retention, heating characteristics, and reusability were all considered, the diatomaceous earth materials and the 6.0-pound-per-cubic-foot quartz felt were the best of the materials investigated for the conditions prescribed.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, April 17, 1962

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TABLE I. - HEATING TIMES FOR

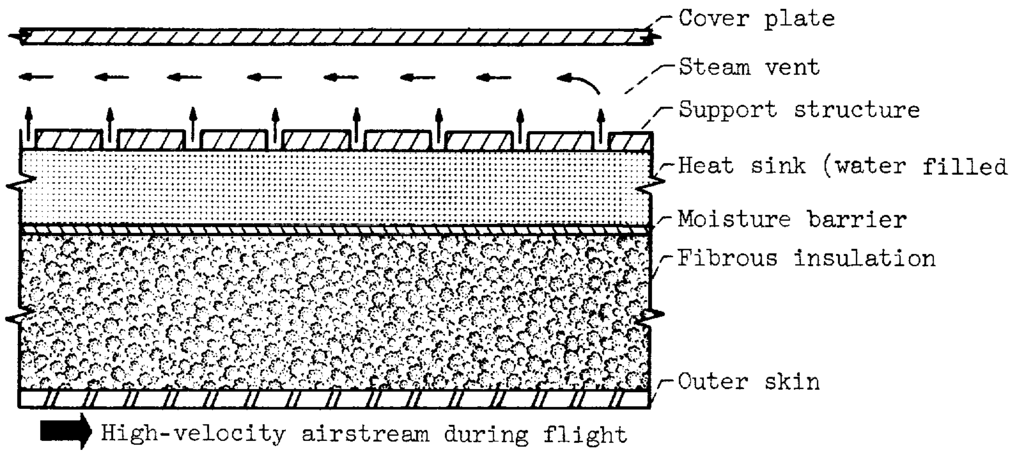
WATER-ABSORBENT MATERIALS

Material	Dry density, lb/cu ft (a)	Heating time, min
Balsa wood, blocks	6.0	110 105
Balsa plywood, four ply	16.5	125
Balsa plywood, seven ply	21.8	126
Blotter paper	21.0	124 123
Diatomaceous earth	23.9	131 132
Diatomaceous earth	13.5	131 129 131
Foamed plastic	1.5	96 85
Foamed plastic	2.1	91 79
Foamed plastic	3.3	91
Glass felt	4.0	87 87 85
Quartz felt	6.0	113 104
Quartz felt	3.5	90 91
Vermiculite	6.3	74 73

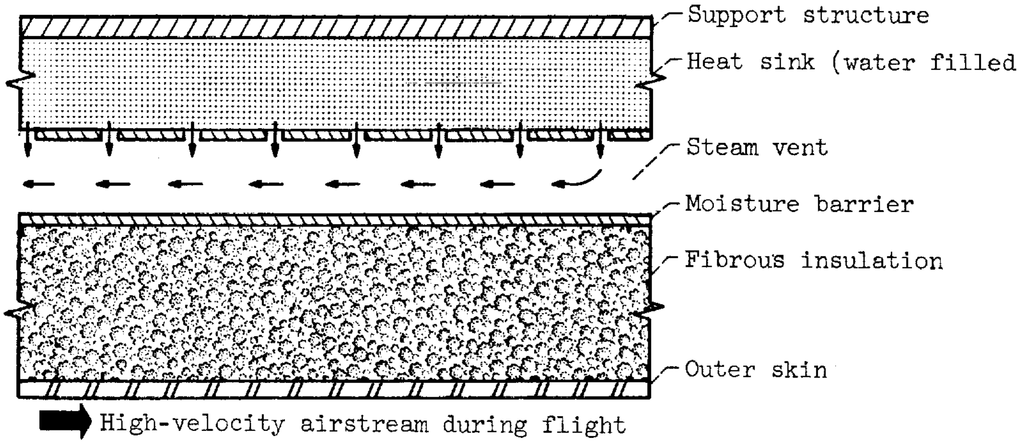
[a]Corrected to wet volume.

TABLE II. - HEATING-TIME FACTORS OF GLASS FELT AND DIATOMACEOUS EARTH (13.5) FOR THE THREE HEAT-SINK SYSTEMS INVESTIGATED

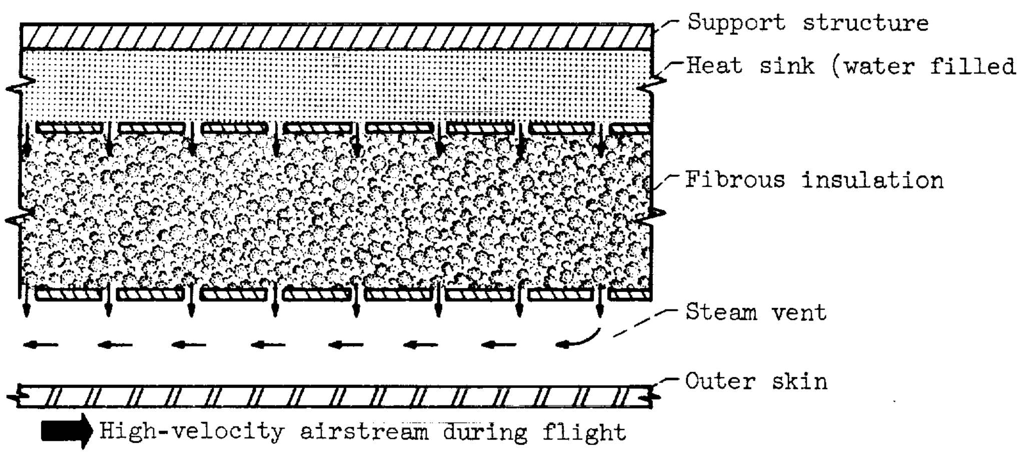
Heat-sink system	Heating-time factor for 1/2-in. thickness, min/(lb)(sq ft)	
	Glass felt	Diatomaceous earth (13.5)
1	38.7 38.5 38.0	44.8 44.1 45.0
2	87.8 89.8 86.3	86.8 85.5 86.0
3	45.8 44.9 39.5	52.3 49.5 47.4



(a) System 1.

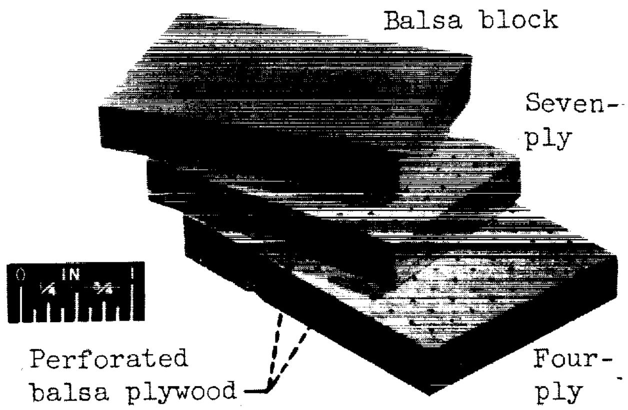


(b) System 2.

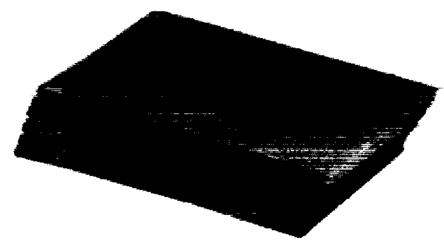


(c) System 3.

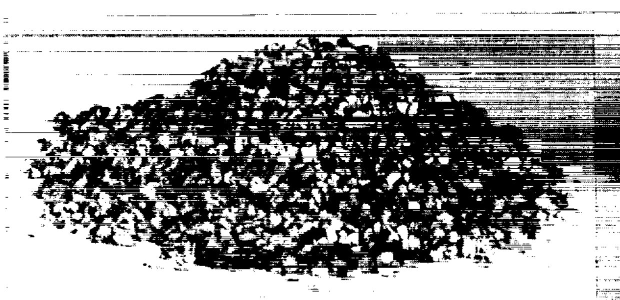
Figure 1. - Schematic diagram of proposed systems utilizing heat-sink cooling.



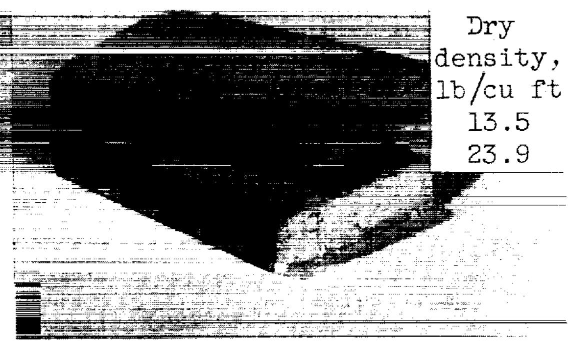
(a) Balsa wood types.



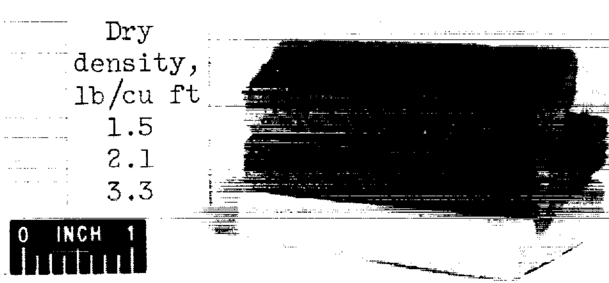
(b) Blotter paper.



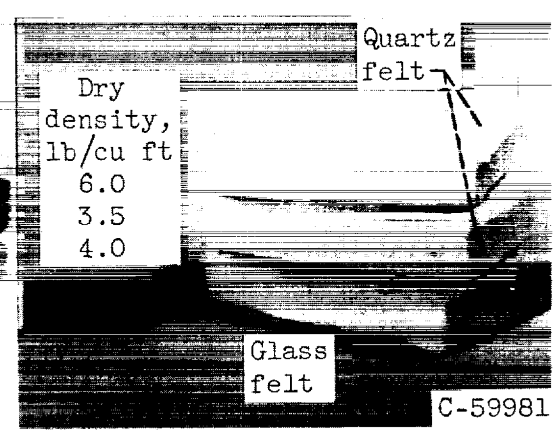
(c) Vermiculite.



(d) Diatomaceous earths.



(e) Porous foamed plastics.



(f) Glass and quartz felt.

Figure 2. - Water-absorbent heat-sink materials tested.

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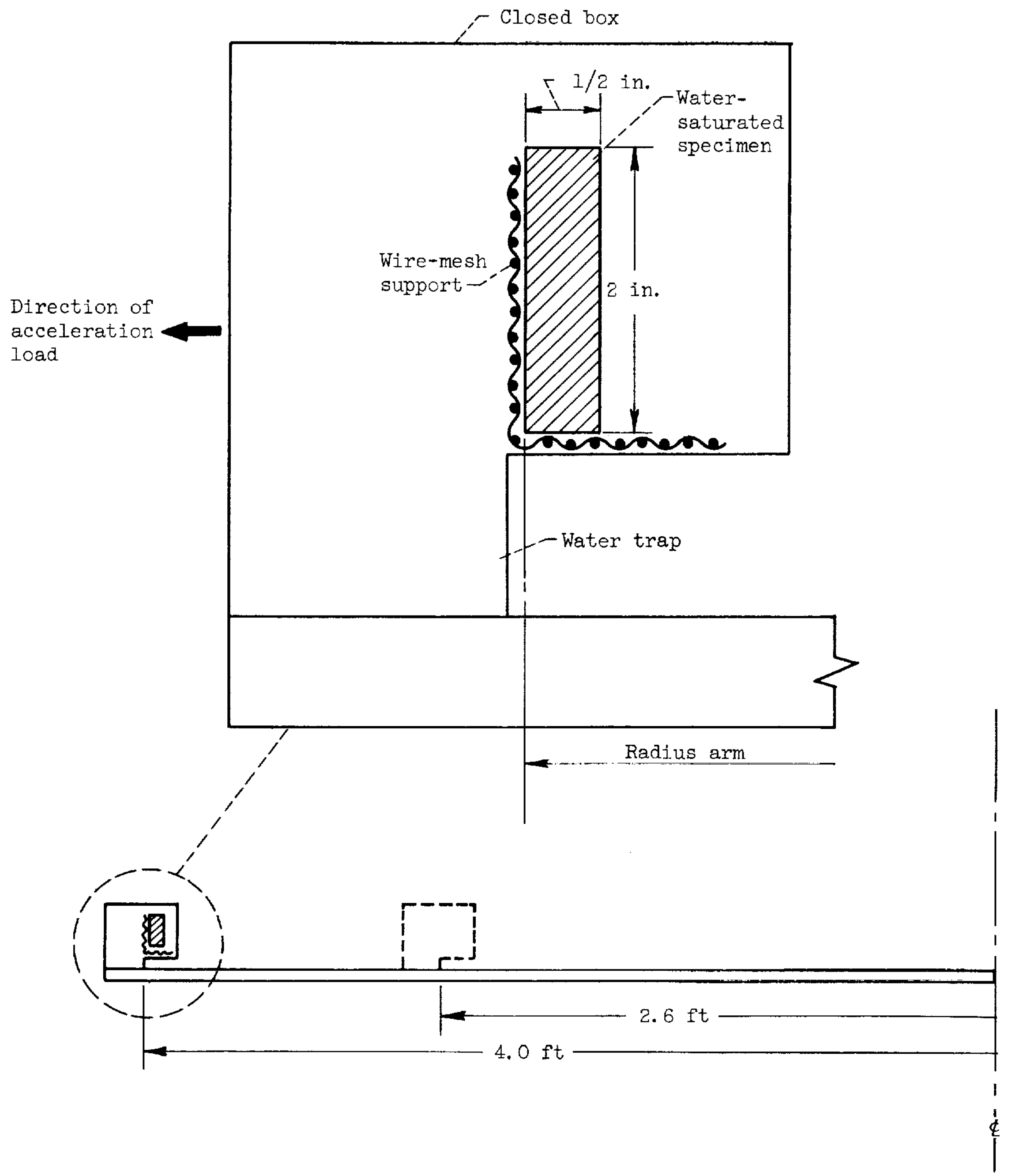

Figure 3. - Schematic diagram of centrifuge used in water-retention tests.

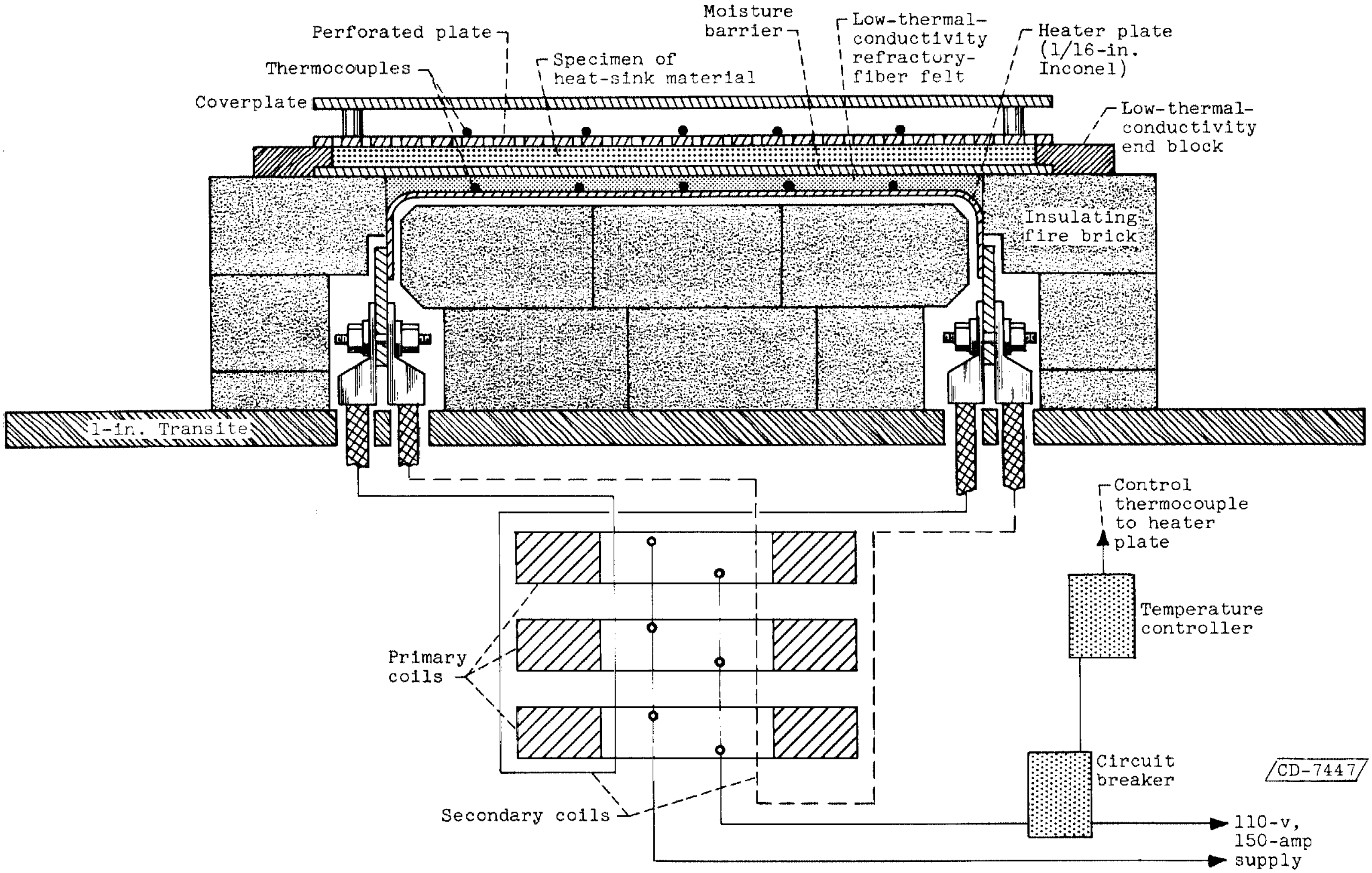

Figure 4. - Electrical heating apparatus used to evaluate water-absorbent heat-sink materials and systems of heat-sink cooling (fig. 1).

	Dry density, lb/cu ft	Wet weight due to absorbent material, percent
Diatomaceous earth	23.9	32.1
Blotter paper	----	29.4
Balsa plywood, seven ply	----	30.6
Balsa plywood, four ply	----	23.4
Diatomaceous earth	13.5	19.3
Quartz felt	6.0	9.1
Balsa wood, blocks	---	9.4
Quartz felt	3.5	6.2
Foamed plastic	3.3	6.1
Glass felt	---	7.5
Foamed plastic	1.5	2.8
Foamed plastic	2.1	4.1
Vermiculite	---	15.9

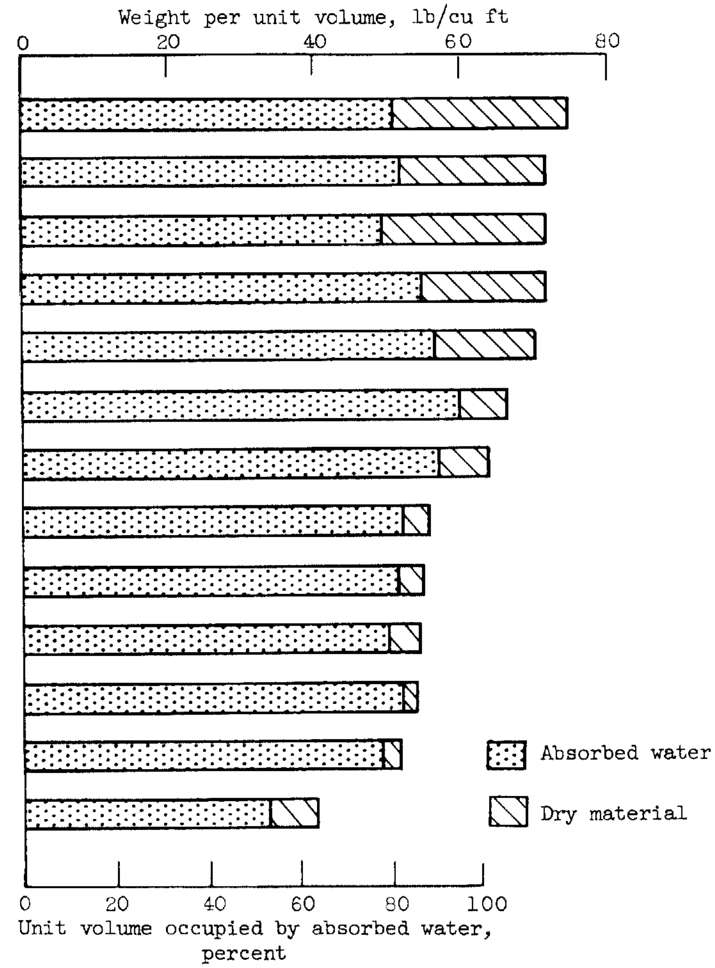

Figure 5. - Weight per unit volume of absorbed water, dry material and wet material.

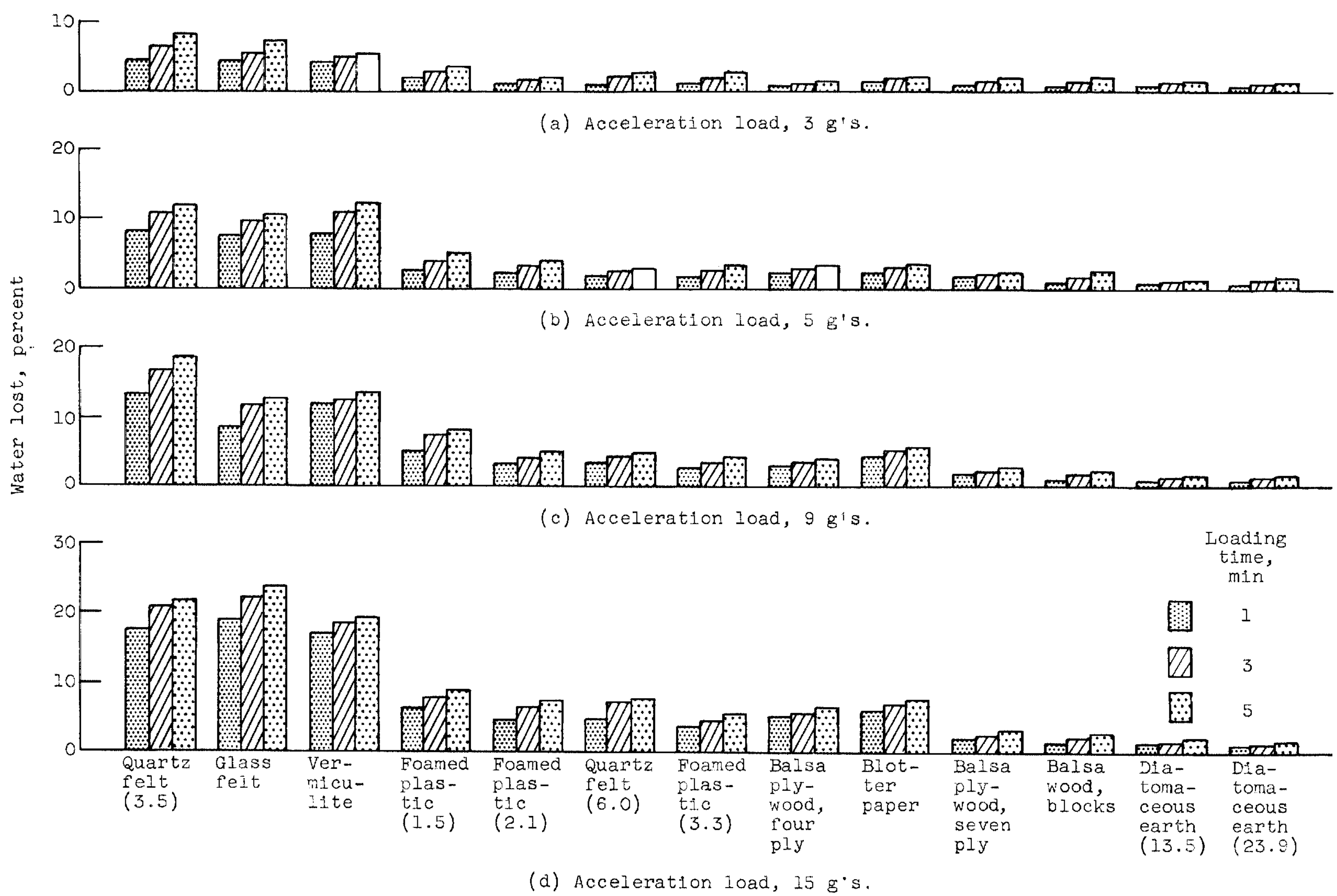

Figure 6. - Absorbed water lost from heat-sink materials under various acceleration conditions.

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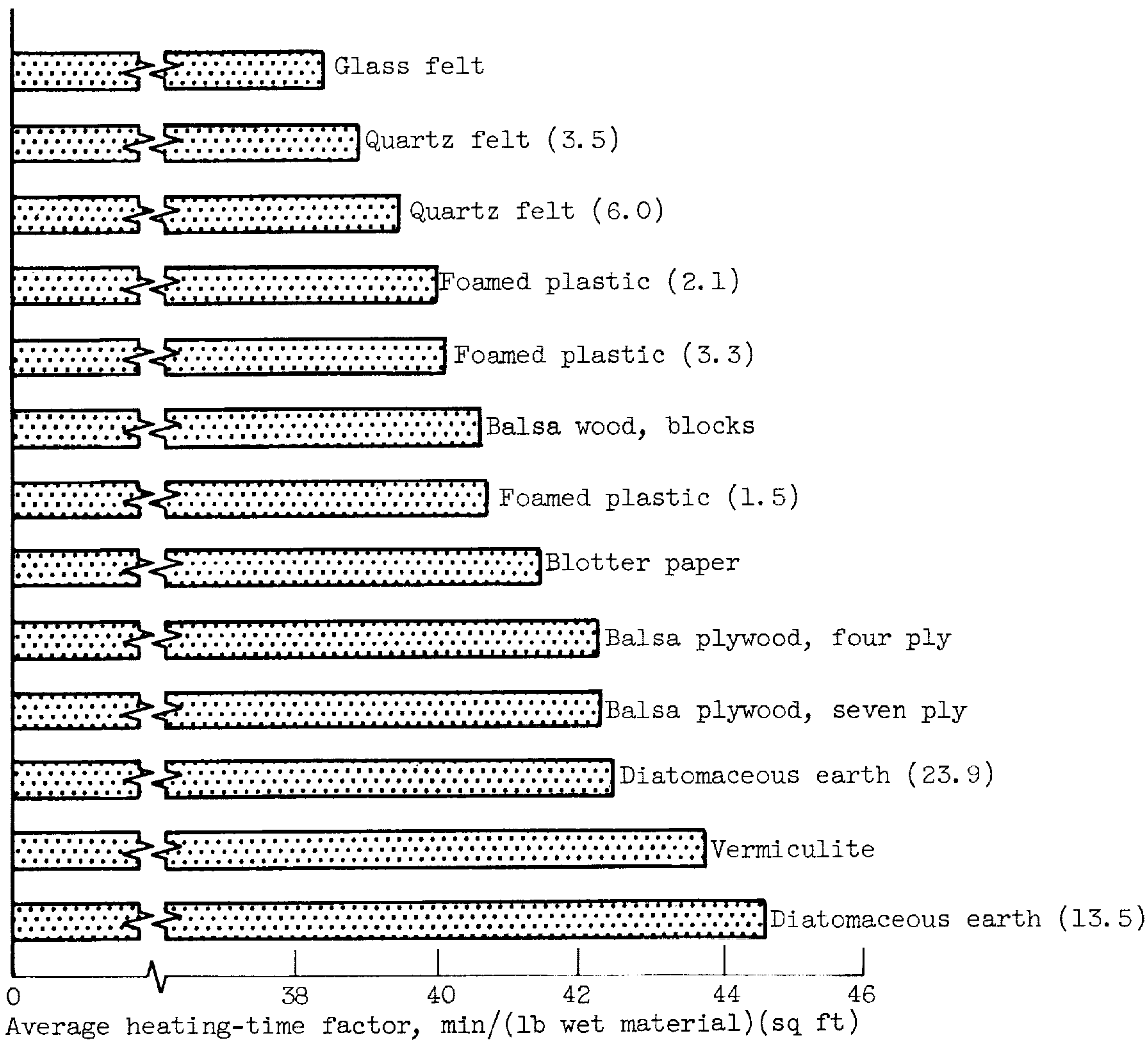

Figure 7. - Comparison of heating tests based upon heating-time factor for water-absorbent heat-sink materials 1/2-inch thick.

NASA TN D-1287
National Aeronautics and Space Administration.
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Robert P. Dengler and Reeves P. Cochran. July 1962. 23p. OTS price, $0.75.
(NASA TECHNICAL NOTE D-1287)

Porous materials saturated with water were considered for cooling low-melting-temperature structural materials in the less severely heated areas of hypersonic and reentry vehicles and for providing suitable environmental temperatures for payloads, such as instrument packages or human occupants. Relative results are presented of tests for determining (1) water-absorption capabilities, (2) ability to retain the absorbed water under acceleration to 15g, and (3) the length of time that thermal protection is provided under simulated aerodynamic heating loads of about 1/2 Btu/(sec)(sq ft).

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